OIL SPILLS FROM A NORTHERN PIPELINE

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Applied Ecology Course, 1972-73

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INTRODUCTION

It is probable that by 1985 a 'hot' oil pipeline will be in operation along the Mackenzie Valley in the North West Territories. The construction of this pipeline will be the result of a basic supply and demand situation. Industrialized society has an ever-increasing need for refined products based on fossil fuels and it is likely that petroleum will dominate Canadian energy markets until the end of this century. Proven reserves of crude oil are diminishing rapidly and it is inevitable that the oil industry will have to utilize the Arctic crude, if the increasing demand is to be met. A pipeline appears to be the most economic method of transporting this oil south (Manhattan Study 1970).

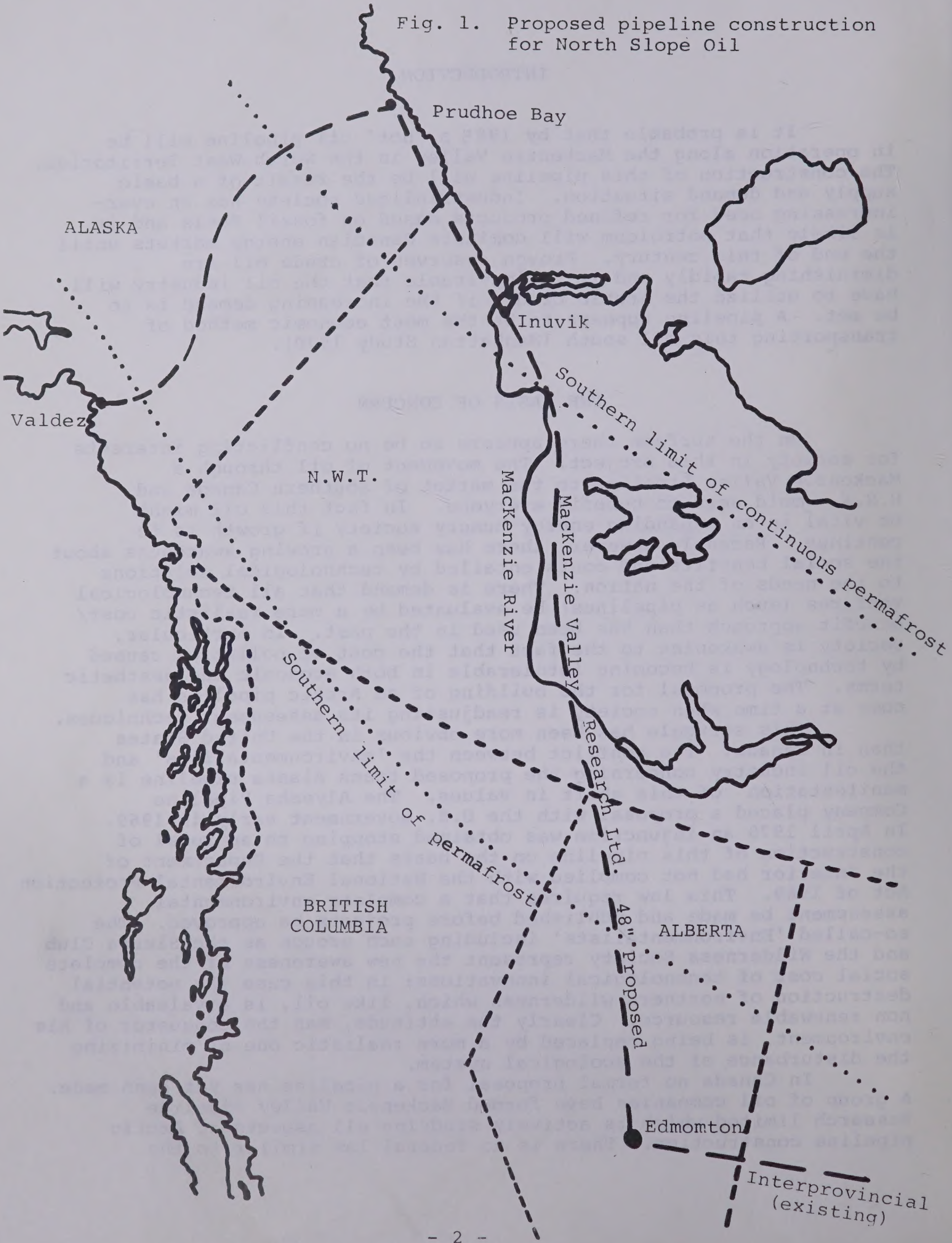
THE BASIS OF CONCERN

On the surface there appears to be no conflicting interests for society in this project. The movement of oil through a Mackenzie Valley Pipeline to the market of Southern Canada and U.S.A. would seem to benefit everyone. In fact this oil might be vital in an expanding energy-hungry society if growth is to continue. Recently however, there has been a growing awareness about the social benefits and costs entailed by technological solutions to the needs of the nation. There is demand that all technological ventures (such as pipelines) be evaluated by a more realistic cost/benefit approach than has been used in the past. In particular, society is awakening to the fact that the cost of pollution caused by technology is becoming intolerable in both economic and aesthetic terms. The proposal for the building of an Arctic pipeline has come at a time when society is readjusting its assessment techniques.

This struggle has been more obvious in the United States than in Canada. The conflict between the 'environmentalists' and the oil industry concerning the proposed trans Alaska pipeline is a manifestation of this shift in values. The Alyeska Pipeline Company placed a proposal with the U.S. government early in 1969. In April 1970 an injunction was obtained stopping th approval of construction of this pipeline on the basis that the Department of the Interior had not complied with the National Environmental Protection Act of 1969. This law requires that a complete environmental assessment be made and published before projects be approved. The so-called 'Environmentalists' including such groups as the Sierra Club and the Wilderness Society represent the new awareness of the complete social cost of technological innovations; in this case the potential destruction of northern wilderness which, like oil, is a valuable and non renewable resource. Clearly the attitude, man the conqueror of his environment, is being replaced by a more realistic one of minimizing the disturbance of the ecological system.

In Canada no formal proposal for a pipeline has yet been made. A group of oil companies have formed Mackenzie Valley Pipeline Research limited which is actively studying all aspects of Arctic pipeline construction. There is no federal law similar to the

Fig. 1. Proposed pipeline construction for North Slope Oil


Prudhoe Bay
ALASKA
Inuvik
Valdez
N.W.T.
Southern limit of continuous permafrost
MacKenzie River
MacKenzie Valley Research Ltd.
Southern limit of permafrost
48" Proposed
BRITISH COLUMBIA
ALBERTA
Edmomton
Interprovincial (existing)

Environmental Protection Act of the United States. However the Canadian government is making an intense effort to amass the necessary competence and data required to evaluate such a proposal by early 1973. As in the U.S., any plan for pipeline construction will have to be evaluated in terms of both economic and environmental priorities.

This report is an evaluation of the threat of oil leaks from an Arctic pipeline. In particular it examines whether large or small accidents should be of most concern. As a result of this analysis suggestions will be made concerning design of the pipeline.

OIL SPILLS FROM AN ARCTIC PIPELINE

Canadian Versus U.S. Routes

Although a Mackenzie Valley pipeline might be preferred on an environmental basis it appears that the United States is determined to proceed with the trans Alaska route for economic and political reasons. However it is almost certain that a Canadian line will be built even if the Alaskan one is approved. While the prospect Alaskan crude would enhance such a major undertaking there appears to be a commercial volume of oil in the Mackenzie delta which would make an all Canadian line viable, independent of Alaskan supply. The recent announcement by the federal government of a transportation corridor along the Mackenzie valley further supports this view.

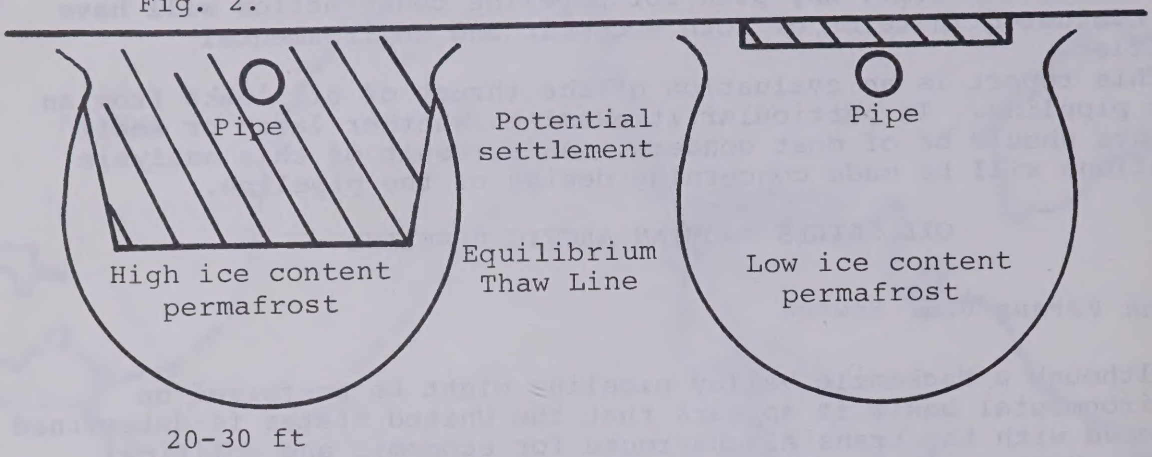
The design of the Alaskan line is far advanced of Canadian studies. In July 1971 the Alyeska Pipeline Company submitted to the U.S. Department of the Interior a three volume Project Description of the Trans Alaska Pipeline System, accompanied by twenty six volumes of appendices. No detailed engineering plans or design work has yet been done in Canada. This report will have to rely heavily on the Alyeska proposal for data. Such an approach can be justified by the strong resemblence of the two pipeline routes (Table 1). They would both face the same basic technical problems; climate, remoteness, permafrost and special considerations for the environmental impact. Thus the design proposals for the Alaskan line can be assumed to be representative of current Arctic Pipeline technology.

TABLE 1.

	Alaska	Mackenzie Valley
Reserves	10 billion barrels	30 billion barrels
Route	800 miles Prudhoe Bay to Valdez	1200 miles Mackenzie Delta to Edmonton or 1700 miles Prudhoe to Edmonton

pipe. Within a few years it would thaw a cylinder of soil 20-30 feet in diameter. (Fig.2).

Fig. 2.



The settlement of the pipeline would be insignificant if the ice content is small in the soil beneath the pipe. However in soils of high ice content uncontrollable stresses on the line could result with a high likelihood of pipe deformation (Peyton 1970). While a completely satisfactory form of insulation has not yet been found the industry is looking at several construction techniques. Three main modes of construction are envisioned for arctic pipelines (Alyeska Project).

Conventional burial. This is generally the safest and most desirable form of construction wherever adequate soils exist (Fig. 3). However it will be unacceptable in many locations. The criteria set by the U.S. Dept. of the Interior is that thermal disturbance must be limited to bedrock, well drained gravel or permanently thawed ground (Oil and Gas Journal 1971).

Above ground construction. In most areas where the melting of permafrost might cause excessive deformation of the buried pipe, or difficult soil stability conditions exist, the line will be put above ground. This requires the supporting of the pipe on pile bents or gravel berms (Fig. 3). The bottom must be two feet above the ground. All sections must be thermally insulated to prevent the oil from becoming too cold (and hence too viscous) during periods of low flow rates or in the event of a winter shutdown.

Special buried construction. When the ground conditions are suitable for neither conventional burial nor above ground construction, a special burial technique will be required (Fig. 3). Various

TABLE 1 contd.

Terrain	Perma Frost - continous in North. Discontinues in Central Region. Generally higher ice content than Canadian route. Two mountain ranges - Brooks and Alaskan. Passes thru two earthquake zones.	Perma Frost - More continous than U.S. route. Discontinues along Mackenzie. No perma-frost below Northern Alberta. Skirts two ranges: Richardson and Mackenzie. Passes thru at least one earthquake zone.
Construction Dates	Earliest start - spring 1974	unknown

In general the Alaskan Line would be more mountainous and have more Seismic danger but the perma-frost conditions may be more severe on the Mackenzie Route.

Causes of Oil Spills

The composite problems of an Arctic pipeline present by far the greatest challenge ever faced by the pipeline industry (Gant 1972). It is not practical to attempt a complete appraisal of such a complex subject as pipeline design. However in order to evaluate the risks involved in the transportation of oil by pipeline it is necessary to examine some aspects of current design work.

One of the most important aspects of a high pressure oil pipeline is that is should be failure safe, that is, the pipeline should maintain its physical integrity over its working life. The cost of a pipeline failure to both the operator and the environment can be high. This is particularly true for an Arctic line. Although steel will form an extremely tough pipe there are still some unknowns (Hood 1971). Rupture can be caused by corrosion or structural defects or by stress created by thermal forces or differential settlement. Also a line can be broken by an external force such as ice or seismic activity.

Corrosion. The leading cause of pipeline leaks is corrosion. About 50% of flow line breaks in existing pipelines can be traced directly to external corrosion (Folger 1973). This is partially a reflection of the fact that many pipeline networks are relativley old and of outdated design with poor corrosion protection. The use of modern pipe with new steels, good coatings, and current protection techniques all promise less serious external corrosion problems in the future. The Alyeska design proposal calls for epoxy coated pipe with cathodic protection (Alyeska Pipeline Service Company 1971). Never-the less corrosion is likely to remain a problem particularly during the warm summer months.

Structural defects. These flaws may be present in a pipeline due to cracks in the walls of the pipe or at the welds between sections. Welding techniques will be very important in the Arctic because of the low ambient temperatures during much of the year. Low temperature increases the rate of cooling of welds and hence the chance of cracking. (Hood 1971). The testing of a pipeline for defects during construction and startup is time consuming and difficult. The Alyeska project proposes to perform radiographic examination on only 10% of the welding done (Alyeska Project). Hydrostatic testing will be carried out on the completed line but this is subject to limitations in leak detection as will be discussed. Thus there is a high probability that a pipeline would go into operation with a number of small structural defects present.

Thermal stress. The crude oil flowing through the pipeline will be approximately 145°F. The soil on the other side of one quarter inch of steel will be near freezing. This steep temperature gradient will build up tremendous longitudinal stresses in the pipe. This would be a particularly serious problem during a winter startup when the pipe itself would be cold. The specifications of pipe which is already on site for the Alyeska line meets or exceeds current standards set by the American National Standards Institute (ANSI) Code B31.4 and the American Petroleum Institute API 5LX (Alyeska Project). However doubt exists whether these standards are adequate for Arctic conditions. It is claimed that API standard 5LX steels are brittle at certain temperatures (Lang 1971). Some experts wonder if any commercially feasible material will be able to withstand the extremes of thermal stress the pipe will encounter (Black 1971). A recent report published in Pravda shows that a Soviet arctic pipeline is springing leaks from thermal stress cracking less than a year after completion (Black 1971). The implications of something similar happening here are enormous.

Differential settlement. A stress occurs if there is uneven and excessive settling of the soil supporting a pipeline. The laying of a hot oil pipeline in permafrost soils has a high potential for this type of problem if design is not adequate.

Arctic crude oil will be hot as it comes out of the ground. By the time it is received from producers at the origin station the temperature will range up to 145°F. The oil will remain hot as it flows through the line due to hydraulic friction.

In permafrost areas heat transfer from the oil in a conventionally buried pipeline would result in the thawing of soils supporting the

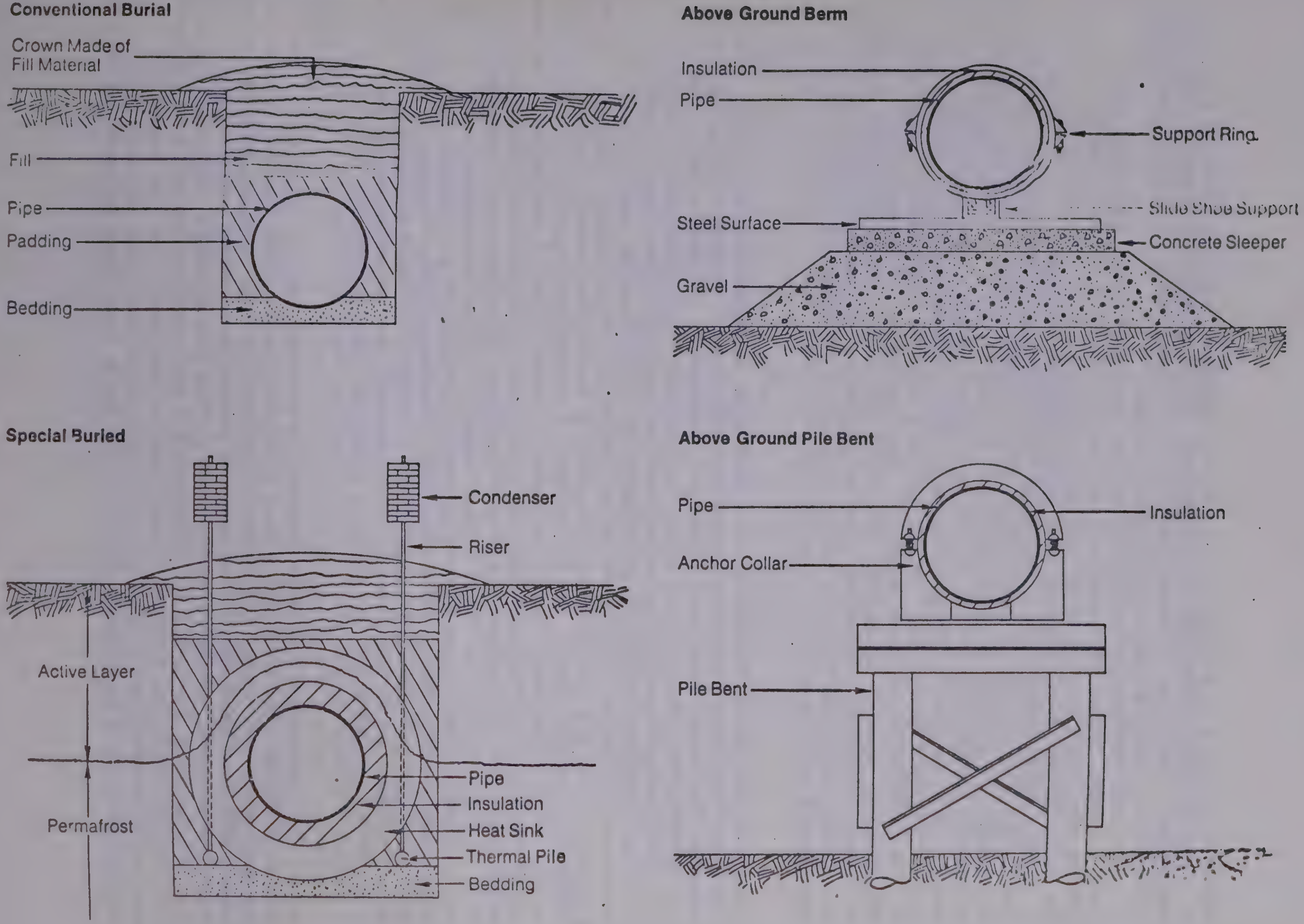


Fig. 3. Construction modes

combinations of ice rich soils, steep slopes, and the possibility of substantial earthquake effects may require special buried construction. Various methods are used to limit heat transfer including insulation, heat sinks and thermal bleeds.

At the Mackenzie Valley Pipeline Research test facility at Inuvik these types of construction were found to significantly reduce the heat transfer to the soil (Research at Inuvik 1971). The rate of soil settlement was considerably slowed.

An important point to be made here concerns the degree of ductility demonstrated by currently available pipe. The deformation required to produce a crack is very large. There is a big margin of safety between the deflection which produces a wrinkle (and hence would necessitate maintenance) and that which would develop a crack (Alyeska Project). While there would be some heat transfer to the soil with current modes of construction, the resulting deformation should be easily detected and repaired before any danger of a leak occured. However such maintenance would be expensive and potentially harmful to the environment. Improved insulation techniques are thus still desirable.

Pipeline fracture. Some of the features of fracture of a high pressure pipeline have important implications. The relationship between the crack size and fracture initiation is important. For any particular steel, pipe size, and operating stress there is a critical defect length above which the fracture will occur. This critical size is surprisingly large; in pipelines at operating pressures it is of the order of six inches. This means that for a pipeline to rupture it must contain a through-the-wall crack about six inches long. If the crack is much less, say three inches long, although the pipeline will leak it will not burst (Hood 1971). At the present time the fracture toughness requirements are more stringent for a gas pipeline than for an oil line. This is because of the high stored energy of the compressed gas and the relatively slow rate that the pressure drops inside the pipe once it has burst. When an oil line bursts the decompression wave outruns the fastest crack and the stress around the crack rapidly drops to a low-level. This causes the running crack to stop after travelling, at most, a few feet (Hood 1971).

Geological hazards. A pipeline could be ruptured by natural forces such as ice scouring, land slides or seismic activity. The magnitude of these dangers will depend on the route selected. These problems have been overcome on previous pipelines and the design will have large safety factors. In the Alyeska Project the special dangers involved in crossing seismic faults (Alyeska Project) and rivers (Alyeska Project) have been minimized. In the areas of potential seismic activity the line has been designed to withstand earthquakes of a magnitude which occur on a long term average of every 200 hundred years (Alyeska Project). At river crossings where ice scour or erosion could be a problem the line will be buried to prevent damage (Alyeska Project).

Leak Detection and Contingency Plans

The proposed Alyeska pipeline would have a control centre at Valdez where the operating conditions would be monitored and controlled. Under some circumstances shutdown of the line would occur automatically, for example if seismometers detected seismic shaking greater than a present value. Under other circumstances such as alarms indicating possible leaks or breaks in the line, the appropriate response would be determined by the pipeline dispatcher (Alyeska Project). It is in the area of leak detection and operator response that potential problems lie.

A check on the absence of leaks by conventional pressure testing or by tracer technique is not easy to perform
The determination of the location of the leak offers additional problems (Basselaar 1971). In the Alyeska project, automatic monitoring of the system parameters at the control centre would provide a continuous means of detecting pipeline leaks (Alyeska Project). They propose to use four automatic alarming methods provided by the computer system-pressure deviation, flow deviation, flow balance deviation and line volume balance. The net effect of the first three methods is that alarms will be sounded if there is a change in pressure or flow by more than 1% of throughput.[1] The fourth method, line volume balance, is expected to provide the means of detecting leaks less than one percent of the flow. This method is one of comparing the volume of oil entering the system against the volume of oil delivered out of the system accounting for all significant variations in the net volume of oil in the pipeline and pump stations. It is expected that after some operating experience is gained, almost all leaks greater than 750 barrels/day can be detected by this method (Alyeska Project). In addition regualar aerial and ground patrols will be made along the pipeline route to detect signs of trouble. Weather permitting air surveillance will be made daily at least during the first months of operation.

With present technology there is difficulty in detecting leaks less than 1% of line throughput and as the leaks get smaller this difficulty in detection increases. The detection of leaks less than 1% relies largely on the interpretation of line performance parameters by the operators. At this level the feedback sensors are operating at or near their limit of reliability. It would be difficult to interpret the data until a significant trend is apparent. Thus a leak even near the 1% level could persist for a considerable time (1 to 2 hours) before it is detected.

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[1] At a flowrate of 2 million Barrels/Day 1% = 800 bbl/hr.

Once a leak is indicated the problem of locating it still remains. Its position can be narrowed down to a particular section of line by the data display. The exact location can only be determined by visual detection. Recent studies of the behaviour of oil spills on Arctic terrain indicate that visual detection may be difficult (Mackay 1972). During the winter hot oil tends to flow beneath the snow and in the summer it flows under the moss layer. Thus there would be little surface disturbance. As soon as aircraft or ground crews pinpoint the leak personnel would be dispatched to close locally operated valves in the area, stop the leak, and begin recovery and repair operations. Thus even with quick visual detection another hour could be lost before the leak is actually stopped. In fact with poor weather the time could be much longer.

Detection of large leaks is much easier and immediate action would be taken to shut down the line. The volume of oil spilt would be limited by the maximum drainage potential of that particular section of pipeline. These maximums could be reached only in the event of a complete rupture or leak of such a magnitude that drainage would be complete before emergency action could be taken to minimize the loss. The Alyeska Project description contains a chart giving its maximum drainage potentials (Alyeska Project).

Maximum Drainage	90,000 Bbl.
2% of line	>70,000 Bbl
10% of line	>55,000 Bbl
50% of line	30,000 → 0 Bbl

Evaluation of the Threat

The effects of oil on ecological systems is currently under intensive study. Numerous workers have described the biological effects of various oil spills in the marine environment. However little work has been done on oil spills on Arctic terrain. Several studies are now in progress which will serve to clarify this important area (Hutchinson and Hellebust 1971).

The potential for danger is enhanced under Arctic conditions because biological processes are very slow and small disturbances can require a long time to right themselves. Man has the capacity ot upset these processes with remarkable ease and with impressive results.

Small versus large accidents. In assessing the potential environmental damage caused by oil spills, the volume of oil released is obviously very important. There are other factors involved such as the location of the leak and the time of year when it occurs. However for the purpose of this analysis of the threat posed by large and small accidents it will be assumed that the potential damage varies directly as the total volume of oil spilt over the lifetime of the pipeline.

The estimated reserves of the Canadian Arctic are approximately 30 billion barrels (Oil Week 1971). Assuming a maximum flow rate of 2 million barrels per day the useful lifetime of a pipeline from the Mackenzie Delta would be of the order of 40 years. A comparison can be made of the potential volume of oil accidently released by large and small oil spills over this period.

It was shown that the chance of a catastrophic break in the pipeline is very low. The danger of rupture by geological forces or differential settlement can be minimized by current design knowledge One such occurance in the lifetime of the pipeline would be highly unlikely. If such a break occurred the maximum volume of oil released could be predicted from a knowledge of the drainage potentials of the line. These values for the Alyeska line are plotted on Fig. 4.

The chance of small leaks is high, particularly due to structural defects and thermal stress. These leaks are difficult to detect and thus are likely to persist for a considerable period of time, ranging from a few hours to days. Assuming that small leaks are those below 1% of the line flow, the amount of oil spilt can be estimated. At a line flow of 2 million barrels a day a 1% leak would amount to 800 barrels per hour. Since a leak of this size should be detected fairly readily emergency action could take place quickly, say within two hours. (Assuming good flying and working conditions). Thus the amount of oil released would be about 1600 barrels. When smaller leaks occur the detection would get more difficult. For the purpose of this comparison it is assumed that as the leak gets smaller, the lower flow rate would be compensated by the longer duration caused by slower detection and remedial action. Thus the loss of oil could remain approximately the same. i.e.:

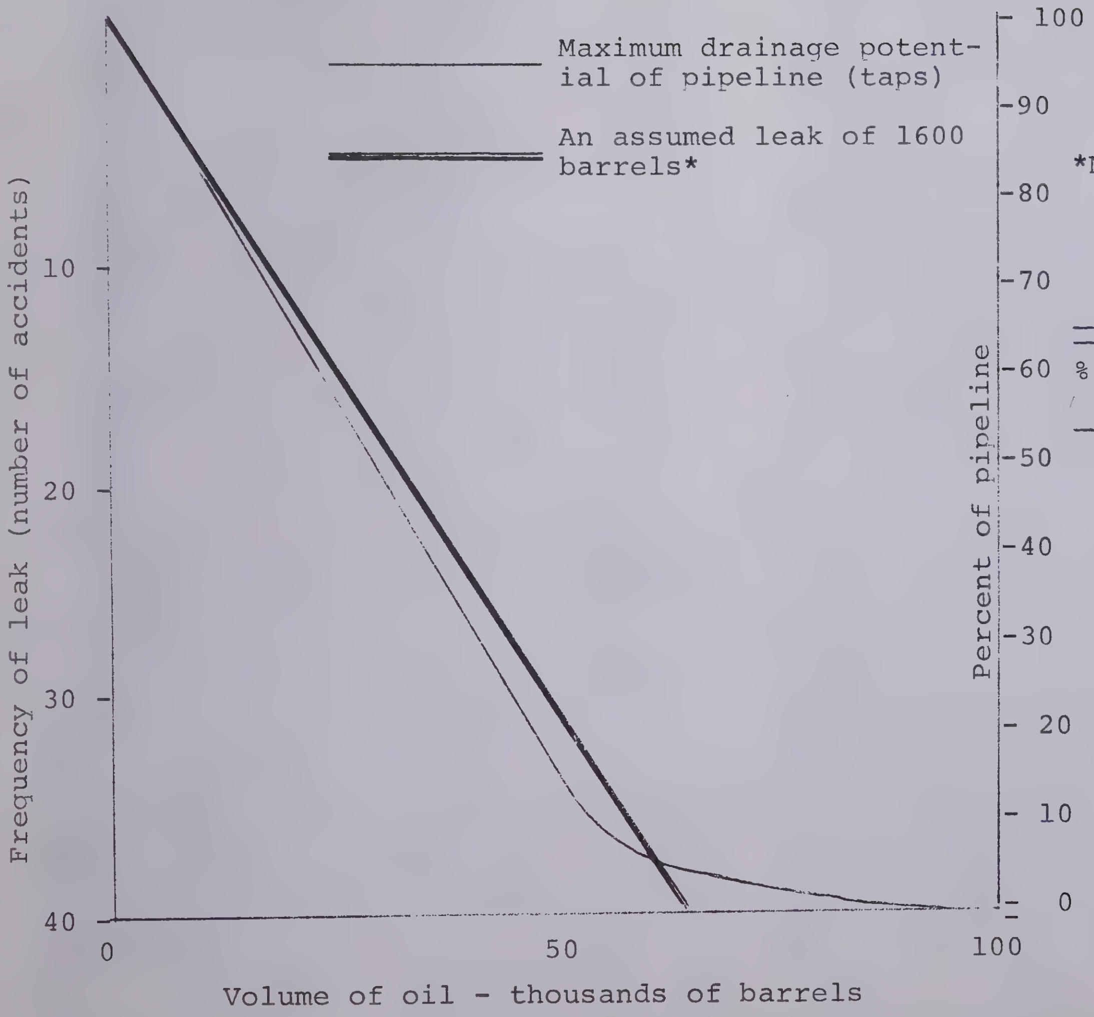
Leak expressed as %

Time flow rate	Leak size	Duration	Volumes spilt
1%	800 bbl/hr	2 hr.	1600 bbl
0.5%	400 bbl/hr	4 hr.	1600 bbl
0.1%	80 bbl/hr	20 hr.	1600 bbl

The important question is how frequently would these small leaks have to occur in order that the amount of oil spilt would equal that which could be released by a complete rupture of the pipeline. Using the volume 1600 barrels, Fig. 3 shows the total volume of a number of these small leaks and the amount spilt by a break anywhere on the line. A typical point shows that to equal one large accident spilling approximately 50,000 barrels requires about 30 small leaks. In terms of an estimated 40 year lifetime for the pipeline this would be equivalent to only one small leak every 16 months. In fact small leaks are likely to occur more frequently than that.

The implications are that small accidents pose a threat equal to if not greater than large accidents. While public concern and design work focuses on the spectre of a massive oil leak on the delicate tundra of the north, the potential danger from small and hard to detect leaks lurks unnoticed.

Fig. 4. Large vs small leaks



*Note: This leak could be formed by one of several "flow rate" and "duration of leak combinations" e.g.

% flow	Leak flow-rate bbl/hr	Duration hrs
.0	800	2
0.5	400	4
0.1	80	20

CONCLUSION

There is reason to doubt that existing materials and techniques can provide a safe pipeline under arctic conditions. No approval for construction should be made until an adequate system can be assured. The first step should be an accurate assessment of the immediate need for Arctic oil from an energy stand point. This will enable a realistic scheduling of research priorities to ensure that the cost of the pipeline in terms of environmental damage is minimized. There is a need for research into several aspects of pipeline design.

RECOMMENDATIONS FOR DESIGN STUDIES

1. There should be more emphasis placed on the prevention of small pipeline leaks. These leaks are now likely to be numerous and thus potentially as dangerous as infrequent large accidents. In particular there is need for improvements in the prevention and detection of structural defects in the pipe. There should be a more rigid standard for the resistance to thermal stress cracking for pipeline steel to be used in the arctic.

2. Investigations should be conducted into the detection of small pipeline leaks. Current technology is weak in this area with the result that small leaks (less than 1% line flow) could persist for a number of hours before detection and repair takes place.

3. Further refinements in insulation techniques is still required to prevent expensive maintenance problems as a result of differential settlement.

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